

Assessment of Environmental and Energy Performance Criteria for Street Lighting Tenders using Decision Support System

A. Sathesh,
Department of EEE,
Eritrea Institute of Technology,
Eritrea.
Email: sathesh4you@gmail.com

Abstract: Ineffective policies, missing technical information, large volumes of inappropriate luminaires, malpractice and several such reasons act as a hinderance for the adoption of LEDs in road lighting design despite being the most efficient sources of light. In national roads, the decision makers are sometimes confused by the low efficacy values of the luminaires. The tools for lighting simulation and projects in street lights require several energy performance indicators as described in EN13201-5 which is a novel system. This paper presents an optimal evaluation technique that involves the environmental criteria and can be implemented in the future energy policy. Evaluation of lighting tender and lighting designs is performed using a decision tool while analysing the significance of these factors. The corresponding offers and their ranking is evaluated by the decision tool. Several environmental benefits as well as improved energy saving can be achieved on implementation of this system. Simulation results shows reduced emission of CO₂ and 75% energy saving using the best solution.

Keywords: Sustainability; Street lighting; Lighting tender; Lighting pollution; LED luminaries; Environmental criteria; Energy efficiency; Energy indicators; Decision tool; Adaptive lighting;

1.Introduction

In public utilities and transport infrastructure, street lighting systems play an important role. Around four billion € are spent consuming up to 35 TWh energy by streets that are illuminated to over 1.6 million kilometres in Europe for public authorities [1]. Upgradation of traditional streetlights are essential for several reasons. When compared to the high pressure sodium (HPS) lamps, the efficiency of LED light sources are high. Several applications worldwide have successfully implemented and tested the LED products leading to a mature market [2]. The cost of power consumption is considerably reduced by the installation of LED lamps and the linked equipment. The EU has banned the High pressure mercury (HPM) lamps which are used over 50% in Greece and 23% in Europe since 2015. This imposes difficulty in maintenance of the corresponding lamps [3]. Adaptive lighting can be enabled by the new version of EN 13201 that helps in achieving improved energy saving. The procedures to improvise the lighting systems on roads face several obstacles in terms of energy upgrades, national laws, technical guides and gap in regulations [4].

Table 1: Consumption of electricity, Emission factor and CO2 emission in Germany, France and Greece

	Yearly electricity consumption (MWh)	Emission Factor (kg CO ₂ /MWh)	CO ₂ Emission (t)
Germany	9468.96	540.1	5130.4
France	-	68.5	650.7
Greece	-	1058.95	10058.9

Several techniques and policies are implemented and national guides are implemented to improve the existing systems of rod lightings by experts using three major directions [5]. They include analysis in technical terms and based on economy; the lighting design planning based street lighting classes are identifies and their operational needs are investigated; and the mapping of the energy consumption associated with the existing lighting installations [6]. The cornerstone of this scheme is the minimization of the emission of CO₂ in transportation and infrastructure of roads by means of street lighting [7]. Several researchers have described the process of street lighting with a step by step methodology for different towns to implement refurbishment designs. However, the major and crucial factors like light pollution, quality of light and enhancement of visual comfort are not considered in prior work [8].

Various issues like lighting pollution are caused by more than 3000 K correlated color temperature (CCT) and inappropriate luminaires that are implemented in certain projects for which the negative effects are reduced by the authorities based on feedback after implementation [9]. In curfew hours, the lighting systems are dimmed up to 50% in Green Public Procurement Criteria thereby reducing the negative effects due to light pollution [10]. The current total harmonic distortion (THD) and power factor (PF) is affected greatly due variation in the amount of energy saving of LED products and LED luminaires caused by the dimming curve which is a ratio of the power consumed to the luminous flux [11]. The lighting tenders and the street projects are evaluated based on the electrical characteristics using the luminaires dimming procedure [12].

2. Evaluation Criteria

2.1 Indicators of Energy Performance

Despite the availability of various performance indicators in EN 13201-5, very few indicators are used in simulation tools and lighting studies while selecting the appropriate luminaire by lighting designers [13]. Annual Energy Consumption Indicator (AECI) and the Power Density Indicator (PDI) are the most common indicators. D_P Power Density Indicator (PDI) is given by $D_p = \frac{P}{\sum_{i=1}^n (\bar{E}_i A_i)}$ where the terms P, \bar{E}_i and A_i represent the lighting installation power, average horizontal illuminance maintained and the sub-area size respectively,

2.2 Environmental Criteria

In order to pass the evaluation criteria, the threshold value of Correlated color temperature (CCT) criterion should be less than 3000 K. Other major evaluation factors include light distribution and adaptive lighting. The inclination of the poles and the distance between the poles decides the light distribution [14]. Different LED products offer different dimming curve thereby resulting in different amount of energy consumption. Lower amount of energy consumption is desired in lighting tender ranking system.

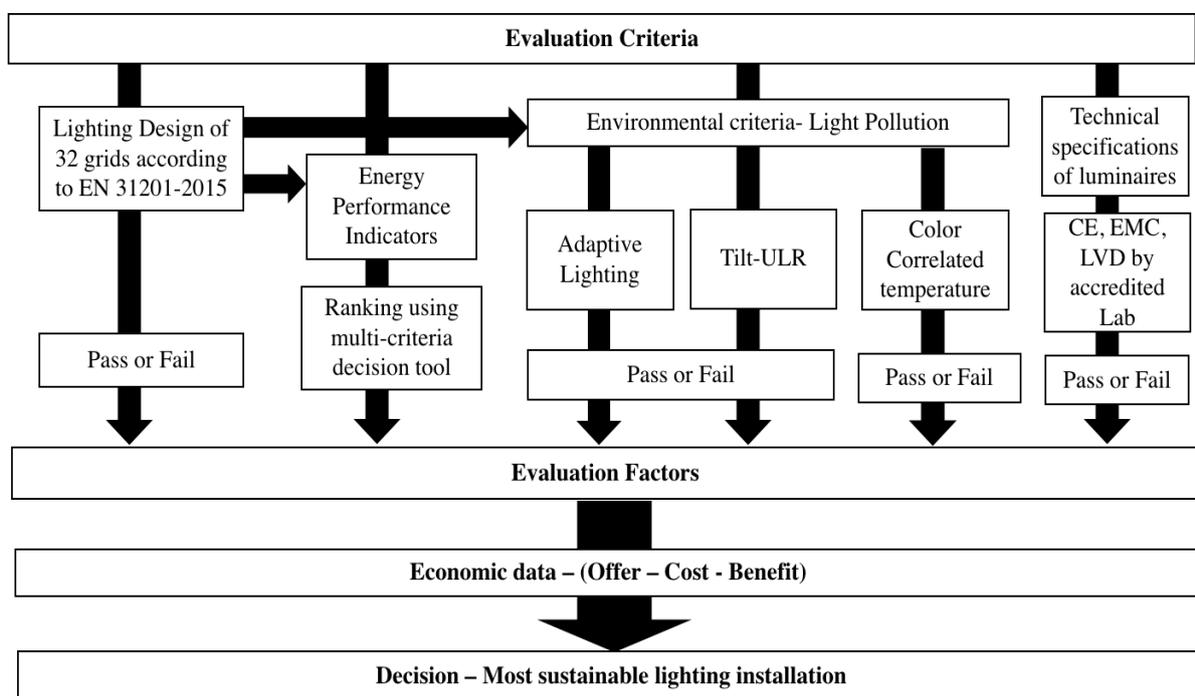


Figure 1: Lighting tenders and their evaluation criteria

3. Methodology

Figure 1 presents the lighting tenders evaluation methodology and evaluation criteria. For primary evaluation four out of twelve available Energy Services Companies (ESCOs) are selected. Evaluation is performed in the selected companies with the following information – Lighting design in terms of lighting class, distance and height of the poles, number of lanes, width of the street and so on, Adaptive lighting design, luminaires dimming characteristics and photometric data, and accredited laboratory based luminaires technical specifications. Extraction of evaluation procedure is done using submitted

technical characteristics and lighting design files along with adaptive lighting dimming power values, luminaire CCT, fixture tilt for evaluation of light pollution, distance between the poles, luminance, illuminance and other photometric quantities, size of each grid and individual luminaire power indicators for evaluation of energy performance.

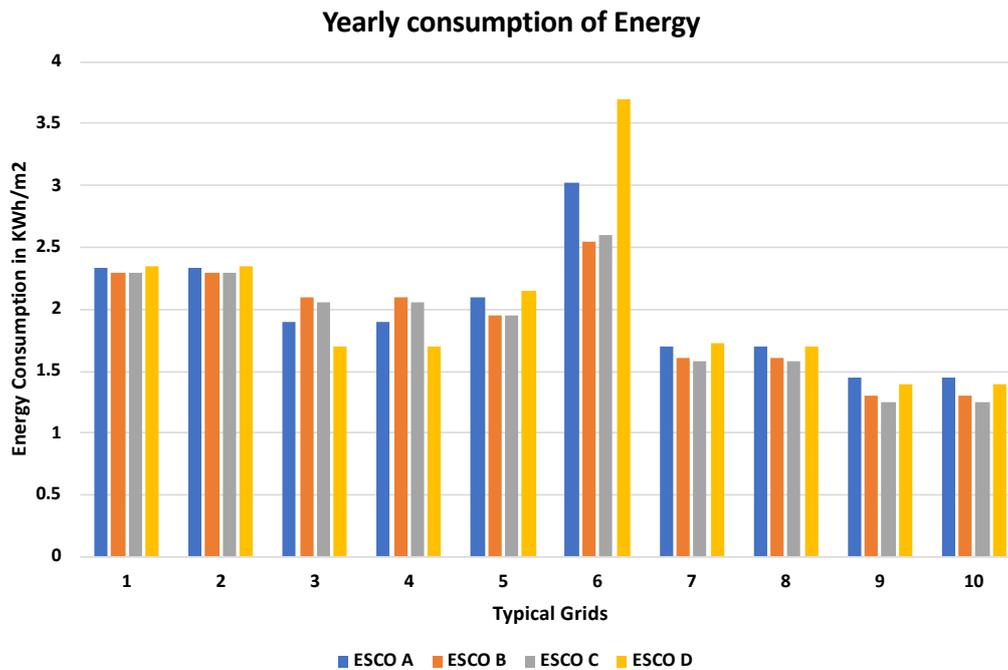


Figure 2: Fluctuation of Power Density Indicator (PDI) values for each ESCO company for the typical grid.

The PROMETHEE technique is used for assessment and calculation of the energy performance indicators and the four ESCOs are ranked based on multi-criteria decision tool. The multi-criteria problems are assessed with evaluation tables using PROMETHEE techniques. Decision makers as well as analysts can understand the clear information provided to run PROMETHEE. The information contained within the criterion and between various criteria is provided here. Within various criterion, the relative importance is represented by the weights that are represented in terms of non-negative numbers that are does not depend on the criteria's measuring units. The importance of the criterion is decided by the weight and are both proportional. The weights compared in this paper for energy performance indicators have similar effect on the ranking.

4. Results and Discussion

4.1 Energy Performance Indicators:

The major energy performance indicators considered in this paper includes Power Density Indicator (PDI), Annual Energy Consumption Indicator (ABCI), Utilance (U), Installation Lighting Factor (ILF) and Installed power to pole distance (IPPD) values. The PDI value comparison graph is represented in Figure 2 with respect to typical grids. The grid geometric characteristics decides the indicator fluctuations in most cases. The ESCO A lighting tender for one grid is better compared to others while the result varies for another grid. The ESCO A ILF is an exception with maximum value of 0.98 while for ESCO B and C, the values are 1.02 and 1.03 respectively. The luminance design values that are less efficient are used in ESCO A whose values for National roadway M classes are greater than 1.

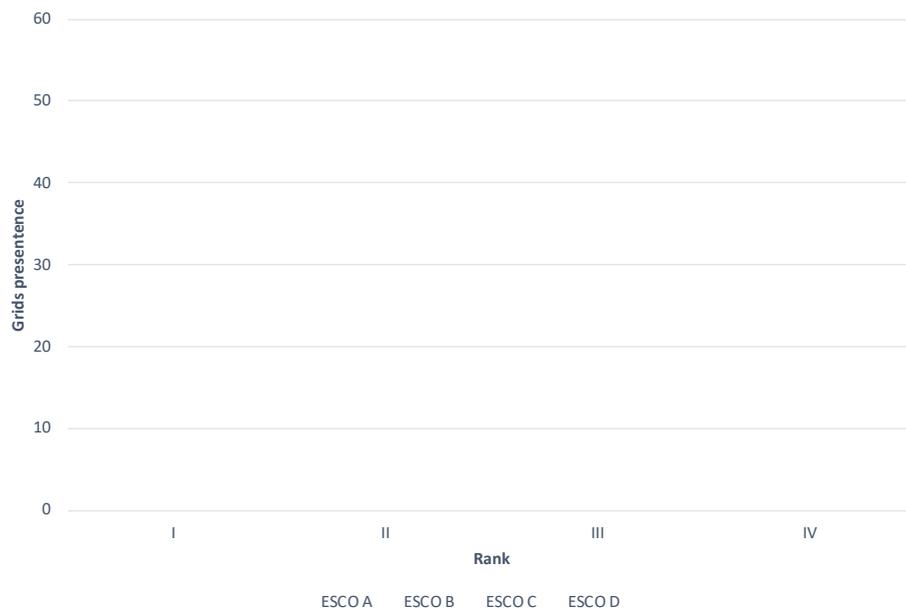


Figure 3: Frequency of the ranking between the 4 ESCOs.

4.2 Decision Tool:

The ESCO ranking is realized on application of the PROMETHEE technique. Every typical calculation grid ranking is noted. A different weight is available for each rank (R). Calculation of weight (W) is performed using the formula $W = 4 - R$. The maximum weight of the corresponding rank is taken into consideration when same rank is available for two ESCOs. For every grid in each ESCO, the distribution

of weight and final sum is analyzed. Based on such analysis, ESCO B and C are found to be eligible as the final ranking of these companies have similar influence by the energy performance indicators. Figure 4 represents the examined ESCO grids and their corresponding energy saving on implementation of adaptive lighting scheme. ESCO B offers most relative power reduction. A comparison of the grids and the total road length is performed for ranking the ESCOs. Large amount of lighting fixtures are used in 4 grids out of the compared 10 grids. Figure 3 represents the ranking frequency between the ESCOs. Figure 4 represents the energy savings with regard to adaptive lighting of the four ESCOs. Light pollution criteria such as inclination and ULR, adaptive lighting and dimming and overall light pollution performance are assessed.

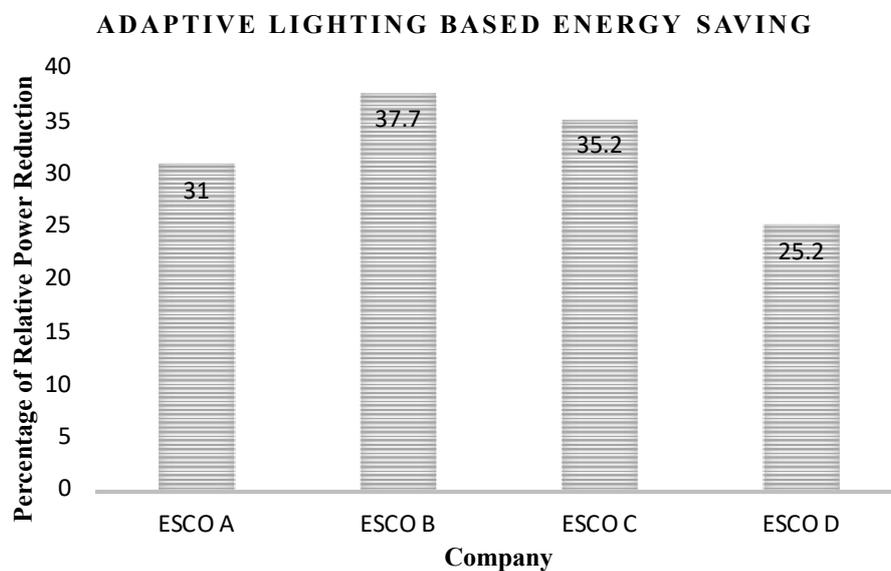


Figure 4: Energy savings with regard to adaptive lighting for the 4 ESCOs.

5. Conclusion

Indicators of energy performance can be implemented as an evaluation criteria in the primary stages of design in lighting systems. The light pollution and its negative effects in the road lighting projects are counterbalanced in this paper. The grey areas of the current energy policies are updated by implementing these factors. On considering these factors, the contractors, lighting experts, municipalities, road authorities, lighting designers and several people involved in the lighting tender will be benefited by this tool. The future energy policies, ongoing technical guides and norms of future lighting tenders can make use of the energy performance indicators calculated in this paper as reference values. AECI and PDI are the major indicators of energy performance examined in this existing research

work. For initial design of lighting systems, the extended indicators of energy performance can behave as standalone factors and significantly influence the design, evaluation and multi-criteria-decision.

In analytical terms, if evaluation is done with the Installed power to pole distance (IPPD) factor and M classes are used, the weight of the PDI must be reduced. On a road project the typical ILF values must be greater than 1. Based on the comparison of the four ESCO ILF values, ESCO A is ranked lower due to the luminance design values and less efficient luminaires. In a specific grid, the utilance is less crucial when compared to the luminaire's luminous efficacy. On comparison of ESCO C and D, the luminaire of ESCO C has lesser efficacy and installed power than the other. The distance between the poles are maintained constant in the renovations, thus making the IPPD more valuable. Removal of intermediate poles improve the pole distance in certain cases, improving the benefits of IPPD.

References

- [1] Polzin, F., von Flotow, P., & Nolden, C. (2016). Modes of governance for municipal energy efficiency services—The case of LED street lighting in Germany. *Journal of cleaner production*, 139, 133-145.
- [2] Power, D. J., & Sharda, R. (2007). Model-driven decision support systems: Concepts and research directions. *Decision Support Systems*, 43(3), 1044-1061.
- [3] Bertoldi, P., & Boza-Kiss, B. (2017). Analysis of barriers and drivers for the development of the ESCO markets in Europe. *Energy Policy*, 107, 345-355.
- [4] Pohekar, S. D., & Ramachandran, M. (2004). Application of multi-criteria decision making to sustainable energy planning—A review. *Renewable and sustainable energy reviews*, 8(4), 365-381.
- [5] Beerepoot, M., & Beerepoot, N. (2007). Government regulation as an impetus for innovation: Evidence from energy performance regulation in the Dutch residential building sector. *Energy Policy*, 35(10), 4812-4825.
- [6] Marino, A., Bertoldi, P., Rezessy, S., & Boza-Kiss, B. (2011). A snapshot of the European energy service market in 2010 and policy recommendations to foster a further market development. *Energy Policy*, 39(10), 6190-6198.
- [7] Anthopoulou, E., & Doulos, L. (2019, September). The effect of the continuous energy efficient upgrading of LED street lighting technology: The case study of Egnatia Odos. In 2019 Second Balkan Junior Conference on Lighting (Balkan Light Junior) (pp. 1-2). IEEE.
- [8] Eom, S., & Kim, E. (2006). A survey of decision support system applications (1995–2001). *Journal of the Operational Research Society*, 57(11), 1264-1278.
- [9] Hermoso-Orzáez, M. J., Lozano-Miralles, J. A., Lopez-Garcia, R., & Brito, P. (2019). Environmental Criteria for Assessing the Competitiveness of Public Tenders with the Replacement of Large-Scale LEDs in the Outdoor Lighting of Cities as a Key Element for Sustainable Development: Case Study Applied with PROMETHEE Methodology. *Sustainability*, 11(21), 5982.

- [10] Jägerbrand, A. K. (2020). Synergies and Trade-Offs Between Sustainable Development and Energy Performance of Exterior Lighting. *Energies*, 13(9), 2245.
- [11] Wang, J. J., Jing, Y. Y., Zhang, C. F., & Zhao, J. H. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and sustainable energy reviews*, 13(9), 2263-2278.
- [12] Wong, J. K., & Li, H. (2008). Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems. *Building and Environment*, 43(1), 108-125.
- [13] Darney, P. E., & Jacob, I. J. (2019). Performance Enhancements of Cognitive Radio Networks Using The Improved Fuzzy Logic. *Journal of Soft Computing Paradigm (JSCP)*, 1(02), 57-68.
- [14] Bindhu, V. (2019). Green Cloud Computing Solution for Operational Cost Efficiency and Environmental Impact Reduction. *Journal of ISMAC*, 1(02), 120-128.

Authors Biography

Prof .Sathish works in the Department of EEE,in Eritrea Institute of Technology,Eritrea. His interested area of research includes modern computer Science and emerging smart technologies in various aspects of Wireless Communications, Cloud Computing, Computer System Engineering, Communication Technologies, Information Processing, Computer Networks, Web Technologies, Computing & Communications, Automation, Image processing and Wireless Communications.